Renewable and Sustainable Energy Reviews 15 (2011) 220–235

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Prospects of dedicated biodiesel engine vehicles in Malaysia and Indonesia

M.H. Jayed [a,*], H.H. Masjuki [a], M.A. Kalam [a], T.M.I. Mahlia [a], M. Husnawan [a,b], A.M. Liaquat [a]

[a] Centre for Energy Sciences, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Department of Mechanical Engineering University of Syiah Kuala, Jl. S. Abd. Rauf No. 7, Darussalam – Banda Aceh, Indonesia

ARTICLE INFO

Article history:
Received 5 May 2010
Accepted 27 August 2010

Keywords:
Palm
Biodiesel
Biodiesel engine
Energy policy
Malaysia
Indonesia

ABSTRACT

Petro diplomacy has played its role in last few decades and that makes energy security a major concern worldwide. Rapid climate change and environmental protection is another vital issue to be addressed in recent energy policies. So an alternative carbon neutral transport fuel is a must in new sustainable energy mix. Biodiesel has immense potentiality to be a part of a sustainable energy mix. In this energy scenario, Brazil's success is a role model in utilizing its agro-industry for reducing poverty, greenhouse gas emission and petro-dependency simultaneously. Brazil commercialized bioethanol in mass scale by introducing flexible fuel vehicles in market. This dedicated engine idea moralizes a new concept of dedicated biodiesel engine vehicles for Malaysia and Indonesia. Southeast Asian countries, i.e. Malaysia and Indonesia is the largest producer as well as exporter of palm oil. Growing at highest yield rate among other biodiesel feedstock, palm based biodiesel is a top exported product for this region. This paper will quantify the prospects of a dedicated biodiesel engine vehicle for Malaysia and Indonesia that will initiate palm based biodiesel in fuel supply chain by leapfrogging the barriers of biodiesel utilization by boosting local automobile industry simultaneously. This article will also review on energy scenario of Malaysia and Indonesia and their renewable energy policies and challenges for coming decades.

Contents

* Corresponding author. Tel.: +60 163827684; fax: +60 3 79674448.
E-mail address: jayedhussan@gmail.com (M.H. Jayed).

1364-0321/$ – see front matter
doi:10.1016/j.rser.2010.09.002

1. Introduction

In the present energy scenario, a complete substitution of petroleum fuels by biofuel is impossible from the production capacity and engine compatibility point of view. Yet, marginal replacement of diesel/gasoline by biodiesel/bioethanol can prolong the depletion of petroleum resources and abate the radical climate change caused by automotive pollutants. Energy security and climate change are the two major driving forces for worldwide biofuel development which also have the potential to stimulate the agro-industry. The Kyoto Protocol emphasized the concept of "carbon neutral fuel"—that is vehicle emissions (CO_2) are offset by using biofuels which is produced from plants absorbing CO_2. Thus the use of biofuel contributes to the prevention of global warming. Asian countries are actively promoting the introduction of biofuels due to energy insecurity and increased energy consumption. The utilization of biofuel is also important from the viewpoint of energy security and environment as well as rural development. Moreover, choice of biodiesel as an alternative fuel for diesel engine is easier from the engineering point of view as it does not require extensive engine modification.

Recently, the use of diesel engine has increased rapidly because of its high efficiency. Nowadays, diesel engines are used in automobiles, power generators, construction and industrial activities. About one-third of the vehicles sold in Europe and in United States are diesel powered. The compress ignition technique of robust diesel engine is fuel economic [1] and emits low pollutants, viz. of CO_2, CO, HC [2]. The inventor Dr. Rudolph Diesel ran his diesel engine by peanut oil at the Paris Exposition in 1900. Its smooth operation on vegetable oil established that, diesel engine is able to run on variety of vegetable oils [3].

Many engine problems are experienced while using raw vegetable oils as fuel, like coking of injectors on piston and head of engine, carbon deposits on piston and head of engine, excessive engine wear [4–6]. To compensate this problem, most researchers [5,7,8] have recommended using transesterification of vegetable oils to reduce viscosity. This transesterified vegetable oil is termed as biodiesel. Biodiesel (Greek, bio, life + diesel from Rudolf Diesel) refers to a diesel-equivalent, processed fuel derived from biological sources. Biodiesel is the name for a variety of ester-based oxygenated fuels from renewable biological sources. It can be made from processed organic oils and fats. In technical terms biodiesel is a diesel engine fuel comprised of monoalkyl esters of long-chain fatty acids derived from vegetable oils or animal fats, designated as B100 and meeting the requirements of ASTM D 6751 [9]. Transesterification is an esterification process of long chained triglycerides of vegetable oils into fatty acid methyl esters (FAME) which is coined as biodiesel. So far, many vegetable oils been used to produce biodiesel, viz. of peanut, rapeseed, safflower, sunflower, soya bean, palm, coconut, corn, cottonseed, and linseed. Also some non-edible oils like Mahua, Neem, Karanja and Jatorpha came into lime light after the fuss of food vs. fuel debate worldwide. But this debate lost its ground as most of the government policies permits only 5–20% biodiesel blend (B5–B20) with petro diesel. Biodiesel have proved its technical soundness in low percentage blending by the field trials and experiments were carried out by researchers in last decade. Therefore, energy conservation and alternative fuels researches are now given high priority in energy planning especially as diesel fuel substitute [10]. Based on many years experience diesel engines are clearly established as the most fully developed and proven approach to improved fuel economy and hence reduced greenhouse gas exhaust emission for automotive engines.

The palm oil production area is mainly tropical Southeast Asian countries. Malaysia has the leading position in terms of the production and export. It produces about 55% of world's palm oil and exports 62% of worlds palm oil export in the form of cooking oil and oil products. It has become one of the most crucial foreign exchange earners of this country. The total export earnings for the palm oil products increased by 160% to US$ 9.50 billion in 2005 from US$ 3.00 billion in 1996 [11]. The palm oil production area has increased from 38,000 ha in 1950 to about 4.2 million ha in 2005, occupying more than 60% agriculture land of Malaysia. The rapid expansion in the oil palm cultivation resulted in a corresponding increase in the palm oil production from less than 100,000 tonnes in 1950 to 16.28 million tonnes in 2005. The oil palm yields on average 3.66 tonnes/ha of oil per year [12].

Malaysian palm oil currently goes into both food (80%) and non-food sector (20%), which includes making soaps and detergents, toiletries, cosmetics, biodiesel and other industrial usages. Various uses of palm oil and its value added products makes its production so profitable that it grabs loins share in world vegetable oil market for decades, as shown in Fig. 1. The Malaysian government has embarked on a strategy to utilize non-petroleum, domestic energy resources to increase self-reliance in energy supply. Indonesia is the second largest producer for vegetable oils especially palm oil. Therefore, since 2006 Indonesia government has decided to use biofuel as energy source for industrial and transportation and targeted to replace 10% of total fossil fuel consumption by 2025 through President decree no. 5 2006 [13]. Based on this instruction, government has also decided to use non-edible source for biodiesel fuel such as Jatropha oil. In addition, Jatropha oil is suitable for the use in diesel engines without converting to biodiesel (methyl ester) through transesterification [14]. Hence, Malaysia and Indonesia have been moved to the next generation of transportation fuels especially for diesel engine since both countries imports huge amount of fossil fuel. Since Malaysia has palm oil based biodiesel industry and Indonesia focused on Jatropha, the comparison study based on their current progress of the research on biodiesel is worth to be discussed.

Nonetheless, there are other problems associated with biodiesel usage such as diesel engine compatibility in long term operation and also food security, biodiversity, changes in land use. Moreover, severe corrosion, carbon deposition and wearing of engine parts of the fuel supply system components are also caused while operated by biodiesel. Discussing all this advantages and disadvantages of biodiesel, it is comprehended that, a dedicated biodiesel engine is the ultimate solution for commercializing biofuel. Brazil successfully boosted their bioethanol marketing by introducing flexible-fuel vehicles (FFVs), which have a dedicated engine for both ethanol and gasoline. A similar approach can bring a breakthrough in biodiesel commercialization and production in Southeast Asian counties like Malaysia and Indonesia. So dedicated biodiesel engine could be the key factor in initiating mass

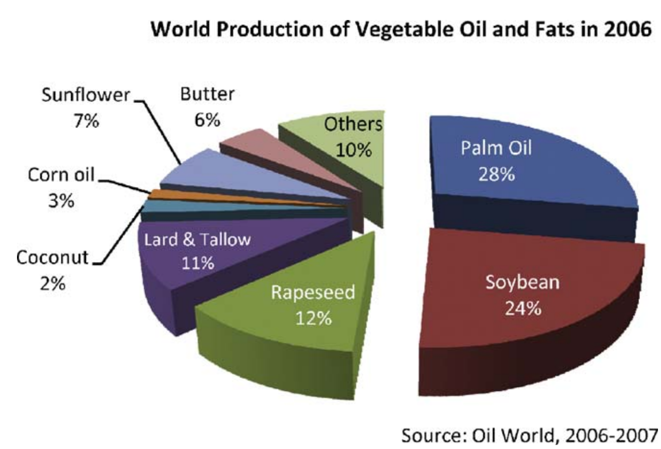


Fig. 1. Global vegetable oil and fat production in 2006.

commercialization and utilization of biodiesel. In this article biofuel scenario of Malaysia and Indonesia is assessed by comparing biofuel policies and standards of other Asian countries and Brazil. Different biofuel processing techniques are also summarized. Some research approached for a dedicated biodiesel engine is described. Minor modifications on the engine may not cost much; but it requires continuous research and development.

2. Biofuel outlook

Asia's largest biofuel producers are currently Indonesia, Malaysia, Philippines, Thailand, People's Republic of China and India [15]. In plain words, Southeast Asian countries along with two economic giants India and China are the only participator in biofuel industry in Asia. Southeast Asian countries are mainly export focused. Whereas new economic giants India and China are taking biofuel programs to keep up with their bullish economic growth and reduce the petroleum dependency.

2.1. Malaysia

Malaysia and Indonesia are respectively largest and second largest producers of palm oil in the world, jointly they produces 85% of world's palm oil. In Southeast Asia (SE Asia) biodiesel production is drastically rising due to its high potentiality and yield factor of palm. Tropical climate and cheap man power of this region is another beneficial point for growing of this plant [16]. Even though Malaysia has taken some initiative to introduce Jatropha production in mass scale, its biodiesel production is still mainly palm oil based. Palm oil is derived from the flesh of the fruit of the oil palm tree *Elaeis guineensis*. Palm tree is originated in West Africa (more specifically Guinea Coast) [17] and initiated in Malaysia in 1870s as ornamental plant and in Thailand before World War II. In both these countries, first commercial plantation started in 1960s [18]. Waste edible oil is another source of biodiesel. Malaysia produces about 0.5 million tons of waste cooking oil every year [19]. A simple purification and conversion process of palm and coconut waste cooking oil can convert this waste into quality biodiesel. But in January, 2009, palm diesel production has accelerated in Malaysia along with Indonesia as palm oil price went down 75% with respect to January 2008 [20].

2.2. Indonesia

According to Indonesia's Ministry of Energy and Mineral Resources, 520,000 tons of biodiesel were produced in 2007, equivalent to 590,000 kL. Based on Indonesia's projection of achieving 2.41 million kL by 2010, the country has achieved 24.4% of its objective. There are currently eight biodiesel plants in the country. By 2011 there will be another 15–17 more, adding 2 million kL of biodiesel production [15].

Table 1
Predicted of palm oil production for year 2000–2020 in MT [23].

Five-year averages	Malaysia	Indonesia	World total
1996–2000	9022	5445	17,932
2001–2005	11,066	8327	23,530
2006–2010	12,700	11,400	29,210
2011–2015	14,100	14,800	35,064
2016–2020	15,400	18,000	40,800

Research at BPPT-LSDE, in Indonesia, has reported a plan to construct 1500 L/day capacity biodiesel producing plant using palm oil wastes. R/D on gasification had resulted in improved domestic manufacturing capability of biomass gasifier capable of producing 15–100 kWe for rice mill and wood mill power supply as well as for rural electrification [21]. Moreover, since 2005 Indonesia also started with huge plantation of *Jatropha curcas* as biodiesel source since this particular oil is non-edible and potential to be converted as biodiesel. It is also one of the strategies by Indonesian government in biodiesel source diversification program [22].

Indonesian bioethanol plants use sugarcane and cassava as feedstock. Whereas, Malaysia's biofuel production is grossly focused on palm oil, which makes Malaysian biofuel industry more vulnerable to volatile petroleum and palm oil (food grade) prices. Nevertheless, palm oil's versatile applications, ranging from food products to green fuel, have made it the most sought after vegetable oil in the world. A subsequent growth of Jatropha oil production could have leaded a sustainable energy security through biodiesel [16]. The predicted palm oil production of Malaysia and Indonesia up to the year 2020 is shown in Table 1.

3. Biofuel policy

Brazil is the world's second largest producer of ethanol fuel and the world's largest exporter. Its sugarcane ethanol is the most successful alternative fuel to date [24]. Brazil's monthly ethanol consumption peaked at more than 1.4 bn liters (370 m gals) in August 2007, as local demand for the biofuel continued to boom, thanks to growth in probably the only other sector in the country that is expanding as fast as the biofuel industry—the flexible-fuel vehicle (FFV) market. Since 1976 the government made it mandatory to blend anhydrous ethanol with gasoline, fluctuating from 10% to 22% [25]. Since July 1, 2007 the mandatory blend is 25% of anhydrous ethanol and 75% gasoline or E25 blend. More than 16 million FFVs were sold by Brazil up to July 2009, as shown in Table 2.

The government of Brazil hopes to build on the success of the Proálcool ethanol program by expanding the production of biodiesel which must contain 2% biodiesel by 2008, and 5% by 2013. There are over 16 renowned car manufacturers like General

Table 2
Ethanol flex light vehicles manufacturing in Brazil 2003–2009.

Year	Flex autos produced	Flex light trucks produced	Total light vehicles[a] produced (including exports)	FFV as % of total light vehicles[a]
2003	39,853	9411	1,721,841	2.86
2004	282,706	49,801	2,181,131	15.24
2005	776,164	81,735	2,377,453	36.08
2006	1,249,062	142,574	2,471,224	56.31
2007	1,719,667	217,186	2,801,011	69.15
2008	1,992,217	258,707	3,009,034	74.81
July 2009	1,268,191	162,940	1,670,302	85.68
Total 2003 to July 2009	7,327,860	922,354	16,231,996	50.83

Source: ANFAVEA 2009.

[a] Total light vehicles including autos and light trucks fueled with gasoline, pure ethanol, flex, and diesel.

Table 3
Biofuels policies in selected Asian countries [26].

Country	Targets for 1st-generation biofuels and plans for 2nd-generation biofuels	Blending mandate	Economic measures
(the) PRC	Take non-grain path to biofuel development	Ethanol: trial period of 10% blending mandates in some regions	Ethanol: incentives, subsidies and tax exemption for production Diesel: tax exemption for biodiesel from animal fat or vegetable oil
India	No target identified Promotion of Jatropha	Ethanol: blending 5% in gasoline in designated states in 2008, to increase to 20% by 2017	Ethanol: excise duty concession Ethanol and diesel: set minimum support prices for purchase by marketing companies
Indonesia	Domestic biofuel utilization: 2% of energy mix by 2010, 3% by 2015, and 5% by 2025 Seriously considering Jatropha and cassava	Diesel: blending is not mandatory but there is a plan to increase biodiesel blend to 10% in 2010	Diesel: subsidies (at the same level as fossil fuels)
Japan	Plan to replace 500 ML/year of transportation petrol with liquid biofuels by 2010. Promotion of biomass-based transport fuels	No blending mandate upper limits for blending are 3% for ethanol and 5% for biodiesel	Ethanol: subsidies for production and tax exemptions
Malaysia	No target identified Promotion of Jatropha, nipa, etc.	Diesel: blending of 5% palm oil in diesel	Diesel: plans to subsidize prices for blended diesel
Philippines	No target identified Studies and pilot projects for Jatropha	Ethanol: 5% by 2008; 10% by 2010 Diesel: 1% coconut blend; 2% by 2009	Ethanol and diesel: tax exemptions and priority in financing.
Thailand	Plan to replace 20% of vehicle fuel consumption with biofuels and natural gas by 2012 Utilization of cassava	Ethanol: 10–20% by 2008 (Gasohol 95) Diesel: 5% (B5) mix in 2007 and 10% (B10) by 2011	Ethanol: price incentives through tax exemptions

Motors and Volkswagen making more flexible-fuel cars nowadays. Half the new vehicles sold this year are able to use either pure ethanol or the blend, according to the Sao Paulo Sugar Cane Industry Union.

Brazil's success story could be a good lesson for policy makers of other countries who can easily use their strong agricultural sector on producing green fuel and utilize it thereafter to reduce petro-dependency. Apart from exporting, Malaysia and Indonesia can focus more in utilizing their biodiesel by introducing a dedicated biodiesel engine vehicle. A thorough summarized view on biofuel policies, targets of Asian countries along with Southeast Asia's leading biofuel producers, Malaysia and Indonesia are shown in Table 3.

3.1. Malaysia

Renewable energy was first introduced in Malaysian energy mix from the announcement of Five-fuel Diversification Strategy in 1999. Fluctuation of oil price and supply makes palm based biodiesel a potential substitute of transport fuel. As a consequence of the diversification strategy, oils share in energy mix drastically reduced from 87.9% (in 1980) to 4.2% (in 2000), which is projected only 1% by 2010 [27]. Malaysia's proven oil reserves have declined in recent years and the oil production fell to 693,000 bbl/d in 2008 and 13% decrease from 2006 level. Provided that the production rate is consistent at around 700,000 bbl/d, Malaysia's oil reserves will be exhausted in around 20 years [28]. Diesel oil and petrol together makes two-third of total petroleum demand of Malaysia. From Fig. 2 it is clearly comprehended that, Malaysia's petro-dependency is mostly on diesel and petrol, two main transport fuels.

In order to reduce huge demand of transport fuel the Ministry of Plantation Industries and Commodities of Malaysia introduced its "National Biofuel Policy" in 2006. It has five strategic thrusts and some desired output for immediate and long term policies, as shown in Fig. 3. In the 9th Malaysia Plan (2006–2010) a special concern is given on ensuring a sustainable energy supply by

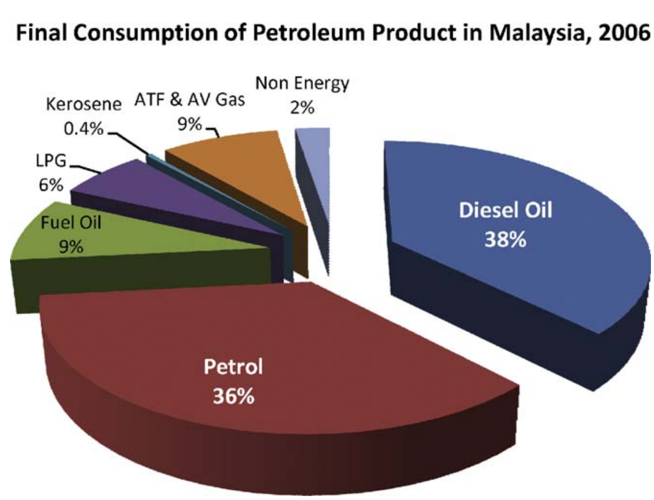


Fig. 2. Demand for petroleum products in 2006, Malaysia [29].

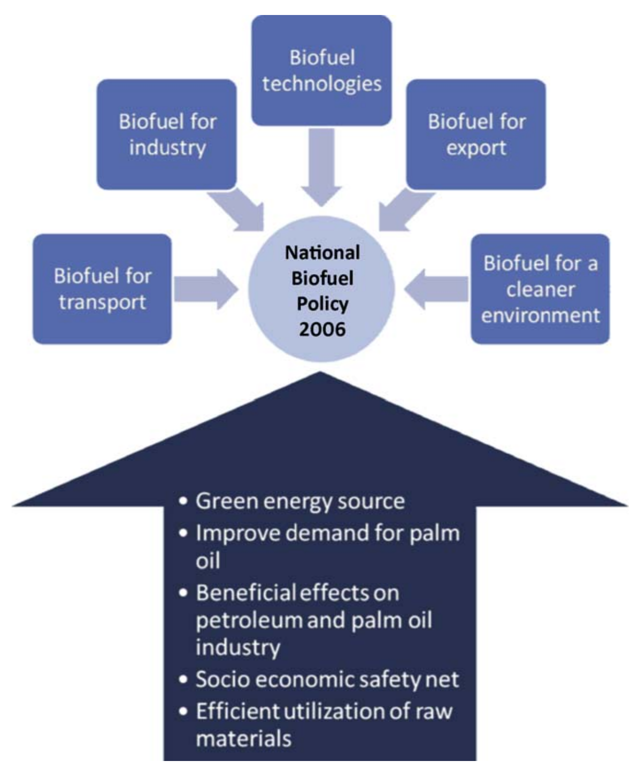


Fig. 3. National biofuel policy 2006 of Malaysia with 5 strategic trust and expected benefits.

enhancing energy efficiency and increasing energy sufficiency which will reduce dependence on petroleum products through the increased usage of alternative fuels such as biofuel and biodiesel as well as renewable energy [27].

Malaysian Palm Oil Board (MPOB) advised the Malaysian government of implementing the use of blended diesel with 5% local refined, bleached and deodorized palm olein as a quick solution for the use as biofuel compared to transforming palm oil to their respective methyl esters which requires more operating cost and time. So, in early 2006, the government launched the B5 (which is the above stated blended diesel with 5% RBD palm olein), or more commercially termed as Envodiesel [30]. However, the situation took a different turn in late 2008, when engine manufacturers decided to apprehend the use of Envodiesel which tempted the government to drop the concerned fuel out of the Malaysian National Biofuel Policy, leaving only the use of palm-based methyl esters dubbed B5 which will be initially used by the government's fleet of diesel vehicles from February 2009. Engine manufacturers had argued that Envodiesel clogs engine in the long run [31]. So redefining Envodiesel to palm oil methyl esters 5% blend with diesel was important for its export in EU meeting their standards which sets B5 as methyl esters blend. The National Green Technology Policy in 2009 has refocused on the use of green technology on the basis of four pillars, energy, environment, economy and social perspective. After this new policy, a ministry is renamed as "The Ministry of Energy, Green Technology and Water" and launched with an aim to co-ordinate ministries, agencies, the private sector and key stakeholders. Malaysian national news agency, Bernama reported (in 29 January, 2010) that B5 programme will be revived in 2011, awaiting cabinet approval. But the barriers for commercializing palm biodiesel still remain. So developing and branding a dedicated biodiesel engine vehicle can really motivate the users in using palm biodiesel.

3.2. Indonesia

The Government of Indonesia established its first national policy on biofuels in 2006 by setting a target of replacing 10% transport fuel by biofuel by 2010. National oil company Pertamina started selling B5 biodiesel blends commercially but suffered serious financial losses due to high feedstock price of biofuel. To compensate losses the blend ration is lowered to 1% now. This phenomenon has plunged the Indonesian government to subside the target to 2.5% diesel excision by biodiesel and 3% gasoline by ethanol in 2010 [32]. Indonesia's roadmap for biofuel development is shown in Fig. 4.

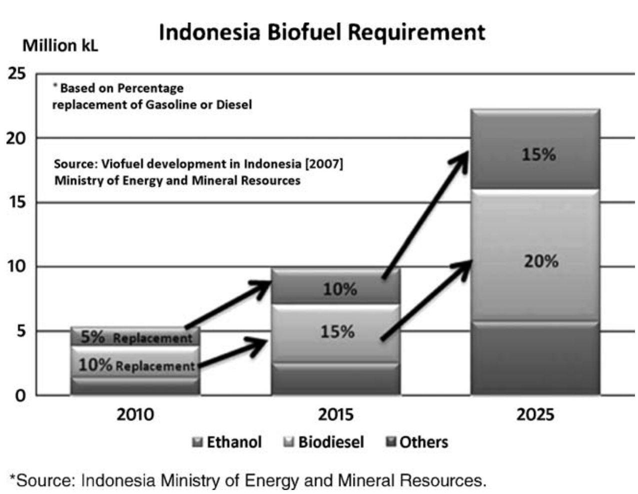


Fig. 4. Indonesia road map for biodiesel development [15,33].

Indonesian government has focused on several strategic points which are targeted to be achieved by 2015 by increasing biodiesel production and utilization simultaneously. Those strategic points are combined and listed below:

1. Job creation for 3.5 million un-employments in biodiesel industries [34,35].
2. Increasing income for On-Farm and Off-Farm workers in biofuel sector up to the regional minimum payment.
3. Development of biofuel plantation in 5.25 million ha unused land.
4. 1000 energy self-sufficient villages especially in 12 special biofuel zone which will be created and started in 2009 [36].
5. Fossil fuel reduction up to 10% (minimum) [37].
6. Accomplishment of biodiesel local demand and export rest [38].
7. Developing investment and finance scheme to support biofuel program [32].
8. Developing price mechanism, starting from feedstock up to biofuel product [32].
9. Increasing local potential.
10. Increasing availability of feedstock and production needs [38].
11. Stipulating biofuel trading system.
12. Accelerate land availability.
13. Promoting *Jatropha carcass* oil and other potential sources as potential biodiesel feedstock.

4. Biodiesel standards and fuel properties

To maintain a standard quality for producing, marketing and storing biodiesel, different biofuel standards are developed and implemented around the world. Among these standards US and EU standards are most dominating and followed by other biofuel producing nations. Even though most standards are similar in limits of sulfated ash, free glycerol content, copper strip corrosion, acid number; they follow different stands in defining fuels sometimes. Such as, biodiesel standards in Brazil and the US are applicable for both fatty acid methyl esters (FAME) and fatty acid ethyl esters (FAEE), whereas the current European biodiesel standard is only applicable for fatty acid methyl esters (FAME). A comparison of biodiesel standards is shown in Table 4. A short discussion on key fuel properties of biodiesel and their standards in EU and US is discussed below:

Flash point: Flash point is a measure of flammability of fuels and thus an important safety criterion in transport and storage. The flash point of petro-diesel fuels is only about half the value of those for biodiesels, which therefore represents an important safety asset for biodiesel. The flash point of pure biodiesels is considerably higher than the prescribed limits, but can decrease rapidly with increasing amount of residual alcohol [39].

EU limit: 120 °C Method: EN ISO 3679
USA limit: 93 °C Method: ASTM D93

Viscosity: The kinematic viscosity of biodiesel is higher than that of fossil diesel, and in some cases at low temperatures it becomes very viscous or even solid. High viscosity affects the volume flow and injection spray characteristics in the engine and at low temperatures it may compromise the mechanical integrity of injection pump drive systems.

EU limit: 3.5–5.0 mm^2/s Method: EN ISO 3104
USA limit: 1.9–6.0 mm^2/s Method: ASTM D445

Sulphated ash: Ash content describes the amount of inorganic contaminants such as abrasive solids and catalyst residues, and the concentration of soluble metal soaps contained in the fuel.

Table 4
Physicochemical properties of biodiesel and biodiesel standards around the world [48].

Property (units)	Malaysia	Indonesia	USA	EU	Brazil	Palm oil methyl ester
	[45]	Indonesian national standardization agency [46]	ASTM D6751 [39]	E 14214 [39]	ANP 42 [39]	[47]
Flash point (°C)	182 min.	100 min.	130 min.	120 min.	100 min.	135
Viscosity at 40 °C (cSt)	4.415	2.3–6.0	1.9–6	3.5–5	–	4.5
Sulphated ash (% mass)	0.01 max.	0.02 max.	0.02 max.	0.02 max.	0.02 max.	0.002
Sulphur (% mass)	0.001 min.	0.001 min.	0.001 min.	0.001 min.	–	0.003
Cloud point (°C)	15.2	18 max.	–	–	–	16
Copper corrosion (3 h, 50 °C)	Class 1	Class 3	Class 3	Class 1	Class 1	1
Cetane number	–	51 min.	47 min.	51 min.	–	54.6
Water content and sediment (vol.%)	0.05 max.	0.05 max.	0.05 max.	–	0.05 max.	0.01
CCR 100% (mass%)	–	–	0.05 max.	–	0.1 max.	<0.01
Neutralization value (mg, KOH/g)	–	–	0.05	0.05	0.08	0.24
Free glycerin (mass%)	0.01 max.	0.02 max.	0.02 max.	0.02 max.	0.02 max.	0.01
Total glycerin (mass%)	0.01 max.	0.24 max.	0.24 max.	0.25 max.	0.38	0.01
Phosphorus (mass%)	–	max. 10 ppm (mg/kg)	0.001 max.	0.001 max.	–	0.001 max.
Distillation temperature	–	<360 °C	<360 °C	–	<360 °C	–
Oxidation stability (h)	–	–	3	6	6	13.37

These compounds are oxidized during the combustion process to form ash, which is connected with engine deposits and filter plugging [40].

EU limit: 0.02% m/m max. Method: EN ISO 3987
USA limit: 0.020% m/m max. Method: ASTM D874

Cloud point: The behavior of automotive diesel fuel at low ambient temperatures is an important quality criterion, as partial or full solidification of the fuel may cause blockage of the fuel lines and filters, leading to fuel starvation and problems of starting, driving and engine damage due to inadequate lubrication. The melting point of biodiesel products depends on chain length and degrees of instaurations, with long chain saturated fatty acid esters displaying particularly unfavorable cold temperature behavior.

EU limit: based on national specifications Method: EN ISO 23015
USA limit: report Method: ASTM D2500

Copper strip corrosion: This parameter characterizes the tendency of a fuel to cause corrosion to copper, zinc and bronze parts of the engine and the storage tank. A copper strip is heated to 50 °C in a fuel bath for 3 h, and then compared to standard strips to determine the degree of corrosion. This corrosion resulting from biodiesel might be induced by some sulfur compounds and by acids, so this parameter is correlated with acid number [39].

EU limit: class 1 Method: EN ISO 2160
USA limit: class 3 Method: ASTM D130

Cetane number: The cetane number of a fuel describes its propensity to combust under certain conditions of pressure and temperature. High cetane number is associated with rapid engine starting and smooth combustion. Low cetane causes deterioration in this behavior and causes higher exhaust gas emissions of hydrocarbons and particulate. In general, biodiesel has slightly higher cetane numbers than fossil diesel. Cetane number increases with increasing length of both fatty acid chain and ester groups, while it is inversely related to the number of double bonds [39].

EU limit: 51.0 min Method: EN ISO 5165
USA limit: 47 min Method: ASTM D613

Water content and sediment: The Brazilian and American standards combine water content and sediment in a single parameter, whereas the European standard treats water as a separate parameter with the sediment being treated by the total contamination property. Water is introduced into biodiesel during the final washing step of the production process and has to be reduced by drying. However, even very low water contents achieved directly after production do not guarantee that biodiesel fuels will still meet the specifications during combustion. As biodiesel is hygroscopic, it can absorb water in a concentration of up to 1000 ppm during storage. Once the solubility limit is exceeded (at about 1500 ppm of water in fuels containing 0.2% of methanol), water separates inside the storage tank and collects at the bottom [40]. Free water promotes biological growth, so that sludge and slime formation thus induced may cause blockage of fuel filters and fuel lines. Moreover, high water contents are also associated with hydrolysis reactions, partly converting biodiesel to free fatty acids and decease the production of ester [41], also linked to fuel filter blocking. Finally, corrosion of chromium and zinc parts within the engine and injection systems [39].

Brazil limit: 0.050 (vol%) max. Method: ASTM D2709
EU limit: 500 mg/kg max. (only water) Method: EN ISO 12937
USA limit: 0.050 (vol%) max. Method: ASTM D2709

Carbon residue: Carbon residue is defined as the amount of carbonaceous matter left after evaporation and pyrolysis of a fuel sample under specific conditions. Although this residue is not solely composed of carbon, the term "carbon residue" is found in all three standards because it has long been commonly used. The parameter serves as a measure for the tendency of a fuel sample to produce deposits on injector tips and inside the combustion chamber when used as automotive fuel [39].

EU limit: 0.30% m/m max. Method: EN ISO 10370
USA limit: 0.050% m/m max. Method: ASTM D4530

Acid number: Acid number or neutralization number is a measure of free fatty acids contained in a fresh fuel sample and of free fatty acids and acids from degradation in aged samples. If mineral acids are used in the production process, their presence as acids in the finished fuels is also measured with the acid number. It is expressed in mg KOH which is required to neutralize 1 g of FAME. Higher acid content can cause severe corrosion in fuel supply system of an engine.

EU limit: 0.50 mg KOH/g max. Method: EN 14104
USA limit: 0.50 mg KOH/g max. Method: ASTM D664

Free glycerin: The content of free glycerol in fatty acid methyl ester (biodiesel) is dependent on the production process, and high values may stem from insufficient separation or washing of the ester product. The glycerol may separate in storage once its solvent methanol has evaporated. Free glycerol separates from the biodiesel and falls to the bottom of the storage or vehicle fuel tank, attracting other polar components such as water, mono-

glycerides and soaps. These can lodge in the vehicle fuel filter and can result in damage to the vehicle fuel injection system [42]. High free glycerol levels can also cause injector coking.

EU limit: 0.02% m/m max. Method: EN 14105/14106
USA LIMIT: 0.020% m/m max. Method: ASTM D6584

Total glycerol: Total glycerol is the sum of the concentrations of free glycerol and glycerol bound in the form of mono-, di- and triglycerides. The concentration depends on the production process. Fuels out of specifications with respect to these parameters are prone to coking and may thus cause the formation of deposits on injector nozzles, pistons and valves [43].

EU limit: 0.25% m/m Method: EN 14105
USA limit: 0.24% m/m Method: ASTM D6584

Cetane number: The cetane number of a fuel describes its propensity to combust under certain conditions of pressure and temperature. High cetane number is associated with rapid engine starting and smooth combustion. Low cetane causes deterioration in this behavior and causes higher exhaust gas emissions of hydrocarbons and particulate. In general, biodiesel has slightly higher (45–67) cetane numbers than no. 2 diesel (40–45) [44]. Cetane number increases with increasing length of both fatty acid chain and ester groups, while it is inversely related to the number of double bonds [39].

EU limit: 51.0 min Method: EN ISO 5165
USA limit: 47 min Method: ASTM D613

Phosphorus: Phosphorus in FAME stems from phospholipids (animal and vegetable material) and inorganic salts (used frying oil) contained in the feedstock. Phosphorus has a strongly negative impact on the long term activity of exhaust emission catalytic systems [42].

EU limit: 10.0 mg/kg max. Method: EN 14107
USA limit: 10 mg/kg max. Method: ASTM D4951

Distillation temperature: This parameter is an important tool, like ester content, for determining the presence of other substances and in some cases meeting the legal definition of biodiesel (i.e. monoalkyl esters) [42].

EU limit: none Method: not applicable
USA limit: 360 °C Method: ASTM D1160

Oxidation stability: Due to their chemical composition, biodiesel fuels are more sensitive to oxidative degradation than fossil diesel fuel. This is especially true for fuels with a high content of di- and higher unsaturated esters, as the methylene groups adjacent to double bonds have turned out to be particularly susceptible to radical attack as the first step of fuel oxidation [42].

EU limit: 6 h min. Method: EN ISO 14112
USA limit: 3.0 h min. Method: EN ISO 14112

5. Biodiesel processing technology

Biomass processing technologies have a long history of development. All biomass conversion technologies can be subdivided into two major categories, such as, thermo-chemical conversion and biochemical conversion. Pyrolysis, gasification and liquefaction are the common thermo-chemical process to produce syn-oil, bio-syngas and bio-chemicals respectively, from biomass. On the other hand, biochemical conversion processes produces bioethanol and biodiesel. Bioethanol is produced by either fermentation or hydrolysis from different sources like sugarcane, maize, potatoes, wheat, etc. Biodiesel is produced by transesterification process, which is actually an alcoholysis process that converts triglycerides of vegetable oil to fatty acid methyl/ethyl esters by displacing alcohol from an ester by another alcohol [49]. Bioethanol is fungible to petrol which is used in spark ignition engine. Similarly, biodiesel is for diesel which is widely used in compression ignition engines. Classification of biomass processing technologies is shown in Fig. 5.

Transesterification of triglycerides is first conducted by E. Duffy and J. Patrick in 1853. Famous German inventor Rudolph Diesel invented diesel engine in 1893 when his paper entitled 'The theory and construction of a rational heat engine' was published in the same year [3,9]. But modification of transesterification for higher yield rate of biodiesel is tried by several researchers. Basically commercial transesterification is a catalytic method. This catalyst could be either homogeneous or heterogeneous. Homogeneous catalyst is mainly alkaline (sodium hydroxide, sodium methoxide and potassium hydroxide) [50] or, acidic (sulfuric acid, hydrochloric acid and sulfonic acid) in nature [51]. Enzymes, titanium silicates, alkaline earth metal compounds, anion exchange resins and guanadines heterogenized on organic polymers are heterogeneous type catalysts used for transesterification [52]. In Fig. 6 different of transesterification approaches are shown.

5.1. Catalytic method

The catalyst is dissolved into the methanol by vigorous stirring in a small reactor. The oil is transferred into the biodiesel reactor, and then the catalyst/alcohol mixture is pumped into the oil. The final mixture is stirred vigorously for 2 h at 340 K in ambient pressure. A successful transesterification reaction produces two liquid phases: ester and crude glycerin. Crude glycerin, the heavier liquid, will collect at the bottom after several hours of settling. Phase separation can be observed within 10 min and can be completed within 2 h of settling. Complete settling can take as long as 20 h. After settling is complete, water is added at the rate of 5.5% by volume of the methyl ester of oil and then stirred for 5 min, and the glycerin is allowed to settle again. Washing the ester is a two-step process, which is carried out with extreme care. A water wash solution at the rate of 28% by volume of oil and 1 g of tannic acid per liter of water is added to the ester and gently agitated. Air is carefully introduced into the aqueous layer while simultaneously stirring very gently. This process is continued until the ester layer becomes clear. After settling, the aqueous solution is drained, and water alone is added at 28% by volume of oil for the final washing.

Transesterification or alcoholysis is the usual conversion process used to convert triglycerides of vegetable oil to fatty acid

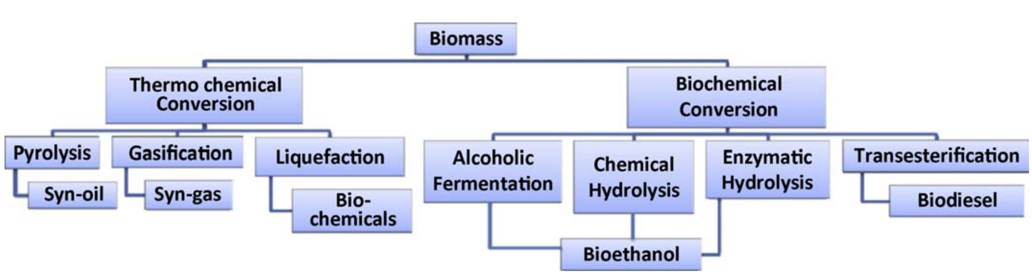


Fig. 5. Classification of biomass processing technologies.

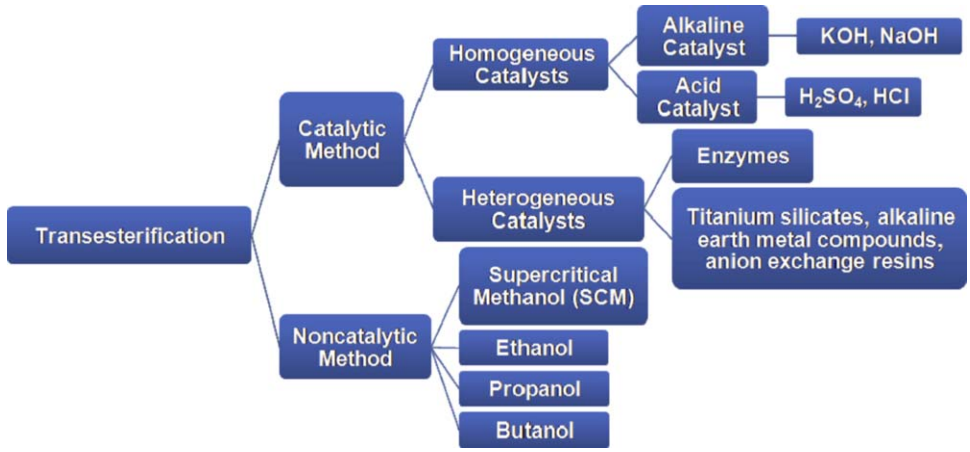
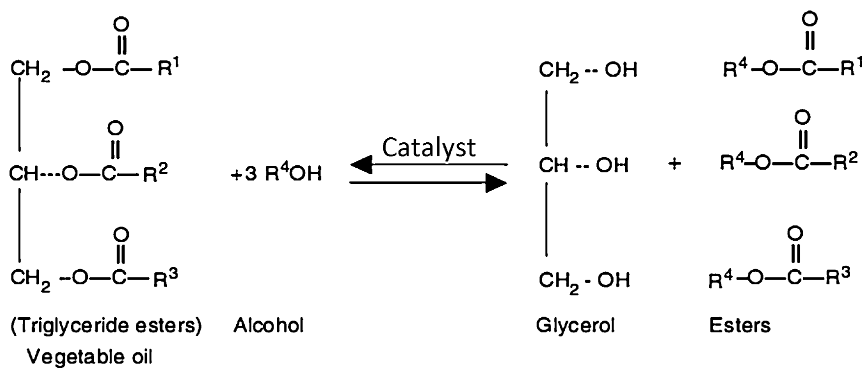


Fig. 6. Classification of transesterification processes.



Triglycerides + 3 Monohydric alcohol ↔ Glycerol + Esters

Fig. 7. Stoichiometric transesterification reaction.

methyl esters (FAME) by displacing alcohol from an ester by another alcohol [49]. For each triglyceride three monohydric alcohols reacts to produce (m) ethyl ester and glycerin (Fig. 7). An access alcohol is used to move this reaction towards production side and catalysts are used to increase the reaction rate and yield of esters. Among alkali, acid and enzyme based catalysts, alkali based catalysts are more effective [5,53] and most widely used in industrial processes for its less corrosiveness to industrial equipment [54]. The glycerin is extracted after dissipating in bottom layer and recycled thereafter for methanol extraction (as shown in Fig. 8).

5.2. Noncatalytic method

The transesterification of triglycerides by supercritical methanol (SCM), ethanol, propanol and butanol has proved to be the most promising process because of its higher yield of biodiesel in short time. A non-catalytic biodiesel production route with supercritical methanol has been developed that allows a simple process and high yield because of simultaneous transesterification of triglycerides and methyl esterification of fatty acids [56]. A reaction mechanism of vegetable oil in SCM was proposed based on the mechanism developed by Kramer and Vogel [57], for the hydrolysis

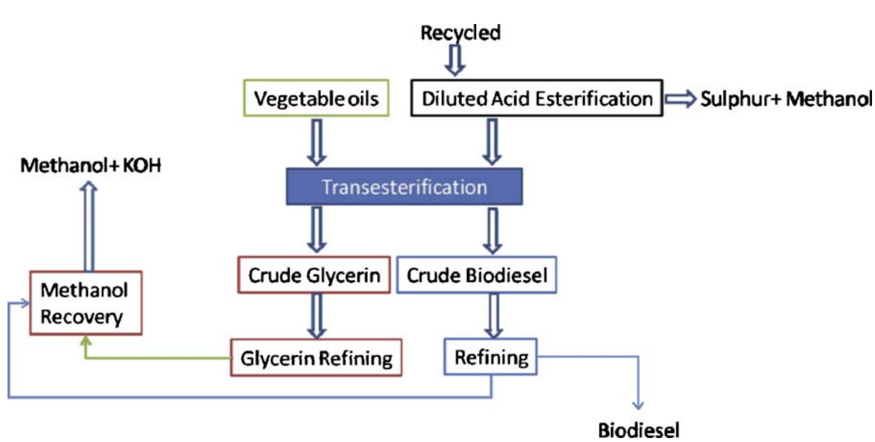


Fig. 8. The basic process schematic of biodiesel production [55].

of esters in sub/supercritical water. The basic idea of supercritical treatment is based on the effect of the relationship between pressure and temperature upon the thermo-physical properties of the solvent, such as dielectric constant, viscosity, specific weight and polarity [58].

Supercritical transesterification is carried out in a high-pressure reactor (auto-clave). In a typical run, the autoclave is charged with a given amount of vegetable oil and liquid methanol with changed molar ratios. The autoclave is heated by an external heater for approximately 15 min. The temperature of the reaction vessel can be measured by an iron-constantan thermocouple and controlled at 5 K (more or less) for 30 min. Transesterification reaction occurs during this period. After each run gas is vented and autoclave is poured into a collecting vessel. All the contents are removed from autoclave by washing with methanol.

5.3. Factors affecting transesterification yield rate

Several aspects like type of catalyst, alcohol to vegetable oil molar ratio, temperature, water content and free fatty acid content have significant influence on the production rate and produced biodiesel quality.

5.4. Difference of catalytic and noncatalytic transesterification reaction

1. Noncatalytic transesterification solves the problem of transesterification by not using any catalyst for reaction and completing the same reaction in shorter time. Conventional transesterification always under goes problems due to foaming caused by free fatty acid and water content which reduces catalyst effectively [59].
2. Another problem of conventional transesterification is its complicated separation process from two phase final product to biodiesel and glycerin, which causes high production cost and energy consumption. The SCM produces a single phase solution as a result of lower value of dielectric constant of methanol in supercritical state. As a result noncatalytic transesterification completes in a very short time saving energy consumption.
3. Noncatalytic process requires higher pressure in autoclave (35–60 MPa) whereas catalytic esterification is done in barometric pressure.

6. Pros and cons of biodiesel

The advantages of biodiesel as a diesel engine fuel are its portability, availability, renewability, higher combustion efficiency, lower sulfur and aromatic content [5,60], higher cetane number, and higher bio-degradability [61,62]. The main advantages of biodiesel given in the literature include its domestic origin, its potential for reducing a given economy's dependency on imported petroleum, biodegradability, high flash point and inherent lubricity [9,63,64].

Being alternative for petro-diesel in transportation sector, biodiesel leads to the easiest and most crucial solution for environmental problems as it does not require critical engine modifications and reduces greenhouse gas (GHG) emission substantially as well as improves lubricity. This makes it more adaptable to current energy scenario to ensure energy security, environmental sustainability, and boost rural development by shifting of power from petro to agro-industry, simultaneously.

Researchers have measured biodiesel performance in engine and found some problems caused by biodiesel. Most of these problems are eminent and caused catastrophic engine failure when straight vegetable oil is used. These problems are summarized in Table 5. But these problems still exist in automotive uses in marginal level, though auto-manufacturers are considering this as main reason for not certifying biodiesel as fuel in their vehicles. Overcoming this problems are challenges for engine manufacturers and researchers in next decade.

Table 5
Problems and causes of vegetable oil run diesel engines [48].

Problems	Causes of problem	Researchers
1. Carbon deposits on piston, piston rings, valves, engine head and injector tips	High viscosity of vegetable oil, incomplete combustion, poor combustion in partial load	Agarwal [4]; Labeckas and Stasys [65]; Ramadhas et al. [66]; Kalam and Masjuki [70]; Ma and Hanna [5]; Nag et al. [67]; Schlick, [68]; Harwood, [6]; Pestes and Stanisalo [69]; Engler et al., [71]
2. Filter plugging, injector coking, nozzle blocking	Polymerization products, impurities, free glycerin, FAME process chemicals (K, Na, detergents etc.)	Labeckas and Slavinskas [65]; Jones et al. [72]; Rathore and Madras [73]; Ryan et al. [74]; Peterson et al. [75]; Pryor et al. [76]; Bruwer et al. [77]; Van der Walt and Hugo [78]
3. Failure of engine lubricating oil	Collection of polyunsaturated vegetable oil, blow-by in crankcase to the point where polymerization	Agarwal [4]; Ma and Hanna [5]; Mittelbach [40]; Perkins et al. [79]; Reid et al. [80]; Schlautman et al. [81]; Harwood [6]; Engler et al. [71]; Hofman et al. [82]
4. Cold weather starting	High viscosity, low cetane and low flash point of vegetable oils	Agarwal [4]; Prateepchaikul and Apichato, [83]; Perkins et al. [79]; Baranescu and Lusco [84]; Sims et al. [85]
5. Heavy gum and wax formation, deposition on piston, piston rings, injectors and cylinder wall	High viscosity, oxidation	Silvico et al. [89]; Zieiwski and Goettler [86]; Tahir et al. [87]; Peterson et al. [88]; Hofman et al. [82]
6. Corrosion of high pressure injecting pump, injectors, injector nozzles, supply or feed pumps, high pressure pipes	Free water, free FAME, corrosive acids (formic and acetic), free methanol, NaOH or KOH particles in fuel, high viscosity at low temperature, iodine value, total acid number, etc.	Brink et al. [90]
7. Fuel delivery problems, poor nozzle spray atomization	Higher viscosity at low temperature	Allsup [91]
8. Elastomer like nitrile rubber softening, swelling, hardening, cracking	Free methanol, free water in mixture	Bosch [92]

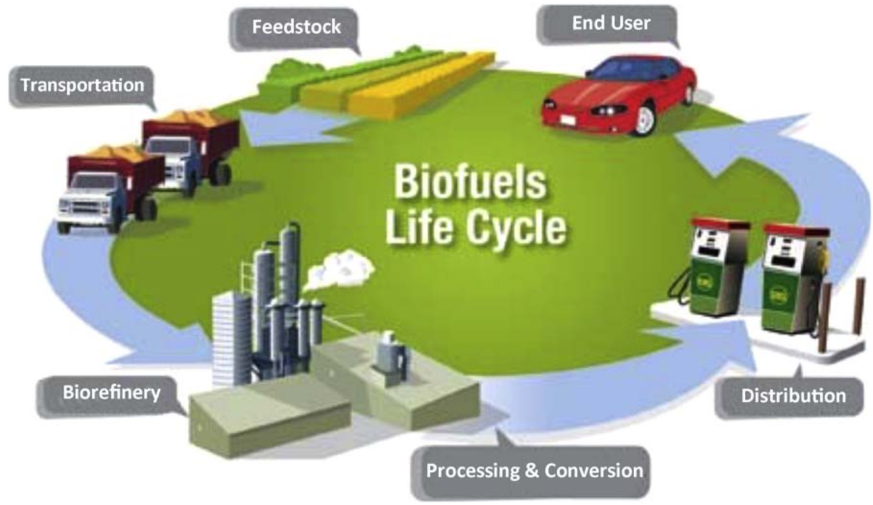


Fig. 9. Life cycle of biofuel from farm to burn.*Source*: Department of Energy, USA.

6.1. Environment and establishment

Being worlds one of the most rapidly expanding crop, palm oil is a threat to biodiversity due to its huge environmental impact triggered by the growing market demand and higher yield factor in Southeast Asian rain forests [93,94]. A national policy to increase palm oil production to keep up with the international demands have paved the way for money lurking businessman to clear rainforest for palm plantation by logging and setting fire in forest. Moreover palm mills create huge water pollutions harming the aquatic biodiversity. Other potential pollutants include palm oil mill effluents (POME), fertilizers, insecticides, rodenticides and herbicides [95,96]. The ecological imbalance created by extension of palm plantation in SE Asian rainforests are causing extinction of Orangutans (in Borneo and Sumatra), haze and peat land drainage [16]. The Malaysian government recently announced that it will ban the conversion of 'protected forests' and 'forest reserves' to oil palm plantations and will only allow areas zoned for agriculture to be developed. Policies should focus not only on higher production rate but also in conservation of forest and environment as well. But similar approach in protecting rainforest by banning illegal logging, forest fires, illegal hunting is not undertaken by Indonesian government. The haze of 1997 created by peat fire contributed 15–40% of global emissions that year [97].

Many researchers have claimed in GHG saving by biofuel, but very few have completely analyzed the total life cycle of biofuel from farm to burn. So comparative factors analysis of life cycle of petroleum based fuel and biofuel is vital to draw a bottom line about GHG saving or increasing. In Fig. 9, life cycle of biofuel is shown.

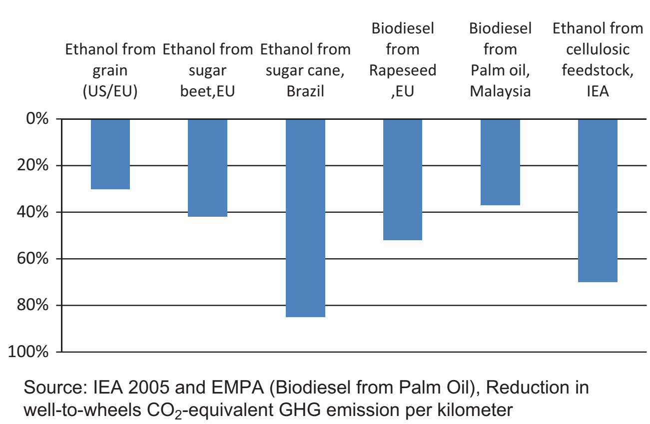


Fig. 10. Estimated GHG reduction from biofuels compared with gasoline and mineral diesel.

Unfortunately, most of the papers put some percentage of GHG savings without mentioning what are the factors they have considered other than a clear comparison of petro diesel vs. biodiesel engine emission only. Grossly, 40–80% reduction of engine emissions is reported by most papers using biofuels, but very few discussed their basis of assessments. An attempt of measuring GHG emission has found 50% reduction while using palm oil in electricity production in comparison to coal based electricity production [98]. Fig. 10 shows a comparison of well-to-wheels CO_2-equivalent GHG emission per kilometer in percentage for different feedstock.

6.2. Troubleshooting biodiesels engine problem

In an effort to determine long term effect of biodiesel on diesel engine some fuel properties of fatty acid methyl esters (FAME) are required to be tailored for long term operation as addressed by many researchers. In an effort to benchmark biodiesel fuel

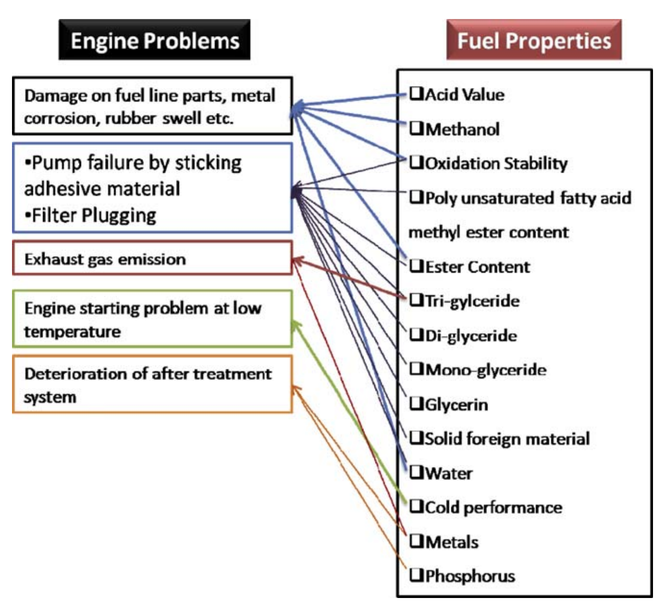


Fig. 11. FAME properties to be remarked and estimated impacts [101].

Fig. 12. (a) Fuel tank used for biodiesel, (b) fuel tank used for biodiesel with oxidation stabilizer [101].

standardizations in East Asia, National Institute of Advanced Industrial Science & Technology (AIST) have experimented on the key fuel properties of FAME and their adverse effect on engine parts. In Fig. 11 some FAME properties and their consequent engine problems are listed. Effect of corrosion is evident on fuel tank while using FAME (Fig. 12). Heavy carbon deposition on cylinder head [99] and injector tip [100] is reported. Fig. 13 shows gradual rise of carbon deposition by the increase of palm olein percentage from 5 to 15 in diesel blend.

Biodiesel have many advantage and disadvantage. But for marketing it, it requires certification from the engine manufacturers as fuel. But many engine fouling and complain caused by biodiesel which are not completely sorted out without engine medication.

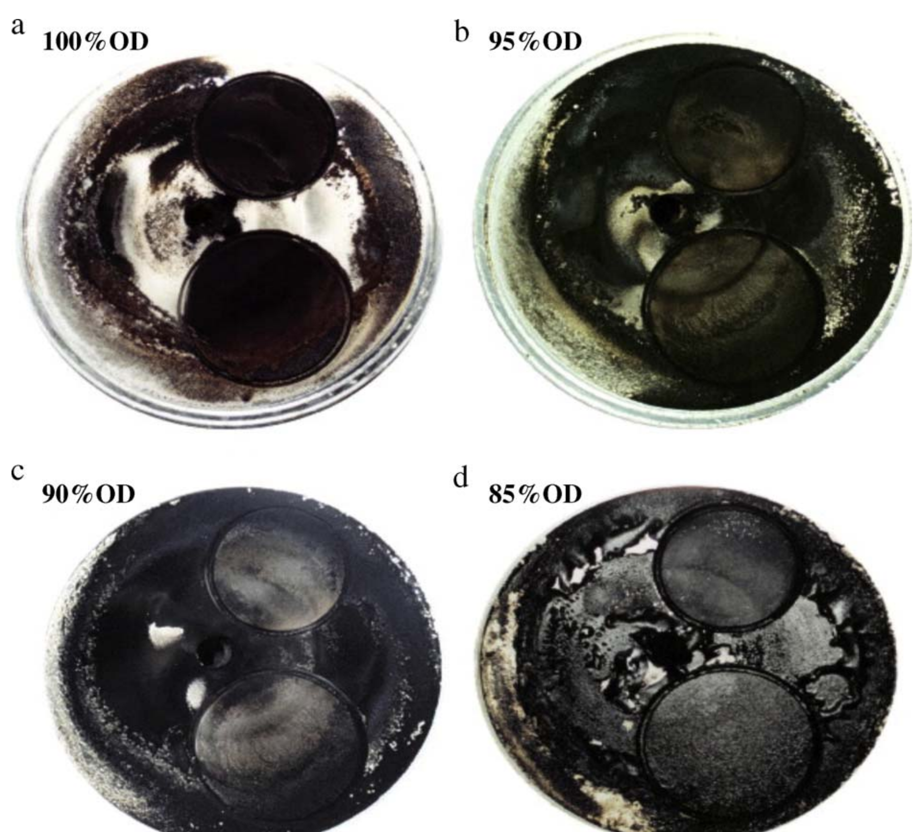


Fig. 13. Cylinder head after using: (a) no. 2 diesel, (b) 95% no. 2 diesel and 5% palm olein, (c) 90% no. 2 diesel and 10% palm olein, (d) 85% no. 2 diesel and 15% palm olein [99].

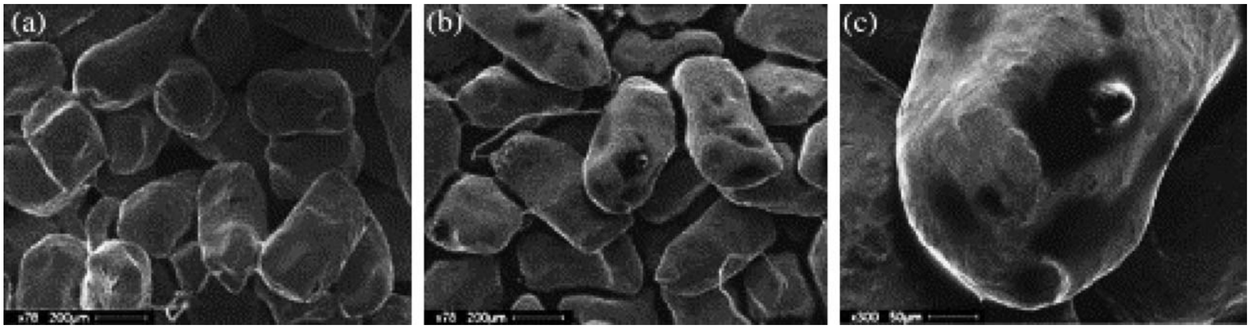


Fig. 14. SEM image of the new (a) and used (b and c) bronze filter. Pitting corrosion appears after several hours of operation with biodiesel at 70 °C [102].

Brazil successfully utilized it vast agricultural resources and used bioethanol in highest proportion by using flexible-fuel vehicle (FFV) or dual-fuel vehicle. Being highly corrosive and hygroscopic, bioethanol caused a lot of engine problems. So FFVs used a different fuel system to adapt with bioethanol (E85). Flex-fuel engines are capable of burning any proportion of the resulting blend in the combustion chamber as fuel injection and spark timing are adjusted automatically according to the actual blend detected by electronic sensors.

Biodiesel have to overcome many challenges to become a feasible substitute for conventional petro diesel. So far biodiesel is commercialized by government and enjoyed high subsidies. Main hurdle in penetrating the market is high production cost of biodiesel relative to petroleum. Major factor determining biodiesels price is its feedstock price [103]. To reduce cost, modification of a high yielding, low cost transesterification process. Agricultural sector with low manpower cost, tropical environment and high yielding oilseed crops are main resources for vegetable oil based biodiesel. From this biodiesel industry, smallholder farmers will be benefited by generating employment and increasing rural incomes, but the scope of those benefits is likely to remain limited with current technologies [104]. Technological advancement through continuous research and development is another challenge.

7. Dedicated biodiesel engine: a comprehensive solution

A modified dedicated biodiesel engine is the only solution to compensate engine compatibly problems caused by high viscous, high cetane number biodiesel. The fuel supply system is required for modification in fuel filter, fuel pump, and adjustment of injection timing by retardation. As biodiesel has higher cetane number, the injection timing should retard as bit to adjust. For low energy content of biodiesel, the engine loses some power, but it runs quieter and the fuel burns cooler, reducing NO_x emissions. Fuel Injection Equipment (FIE) Manufacturers (Delphi, Stanadyne, Denso, and Bosch) showed their concern on the following fuel properties of biodiesel:

- *Free methanol*: Corrosion of fuel injection equipment.
- *Dissolved and free water*: It causes reversion of biodiesel to fatty acid and finally results to filter plugging.
- *Free glycerin*: Free glycerin corrodes non-ferrous metals, soaks cellulose filters, sediments on moving parts and Lacquering which causes filter clogging, injector coking.
- Mono and di-glycerides.
- *Free fatty acids*: Provides an electrolyte and hastens the corrosion of zinc, salts of organic acids, organic compounds formed. Final result is corrosion of fuel injection equipment, filter plugging, sediments on parts.
- Total solid impurity levels.
- Alkaline metal compounds in solution.
- Oxidation and thermal stability.

Fuel pump also suffers badly while operating in biodiesel blends. A list of fuel pump problems is given below:

- Corrosion of fuel injection equipment components.
- Elastomeric seal failures.
- Low pressure fuel system blockage.
- Fuel injector spray hole blockage.
- Increased dilution and polymerization of engine sump oil.
- Pump seizures due to high fuel viscosity at low temperatures.
- Increased injection pressure.

Even though various research approaches on troubleshooting the problems of biodiesel is carried out, a definite solution for all of this may not be possible without a dedicated biodiesel engine. Like Brazil's flex-fuel vehicles a modified diesel engine for different biodiesel blends (B5–B20) is quite achievable by modifying the fuel supply system (fuel pump, filter, injector, fuel tank, fuel lines and injection controller). Such a project on dedicated biodiesel engine may spur the biodiesel production and use along with automobile sales like Brazil, who produced 17 million FFV automobiles by 2009.

Some suggestions on modifications of a diesel engine to a dedicated biodiesel automotive engine is listed below:

Fuel pump: Pump material (like aluminum alloy, iron based alloy) should be changed to a more corrosion resistive material. To reduce the seizure of the pump, a heating system can be run by radiator's heat.

Fuel filter: As prescribed by many automobile manufacturer and researchers, engine requires quicker fuel filter change while running on biodiesel due to clogging by sediments and wear debris and pitting corrosion (Fig. 14). But this quick disposal incurs cost to user and regular inspection as well. So a reinforced fuel filter container (to prevent the crash of highly viscous biodiesel) and smaller meshed fuel filter which can provide a good solution to this problem (Fig. 15).

Fuel injectors: Jones et al. [72], have recommended that checking for fuel injectors should be at least twice as often for biofuel than that for diesel because of their coking and rapid ageing. As shown in Fig. 16, a carbon deposition on tip of injector is obvious if the fuel contains biodiesel even in minor proportions. To avoid plugging and coke formation, the temperature of the nozzle has to be measured and kept (acting on the cooling water flow rate) below 250 °C [102]. Such a nozzle design is proposed by Sgroi et al. [102], as shown in Fig. 17.

7.1. Research approaches for biodiesel engine

With a view to initiate biodiesel commercialization in mass scale, the first step is to supply and maintain the supply

Fig. 15. The external view of a new fine porous filter element (a) that was damaged during experiments by pure rapeseed oil (b) in comparison with reinforced filter (c) suitable to withstand oil pressure [65].

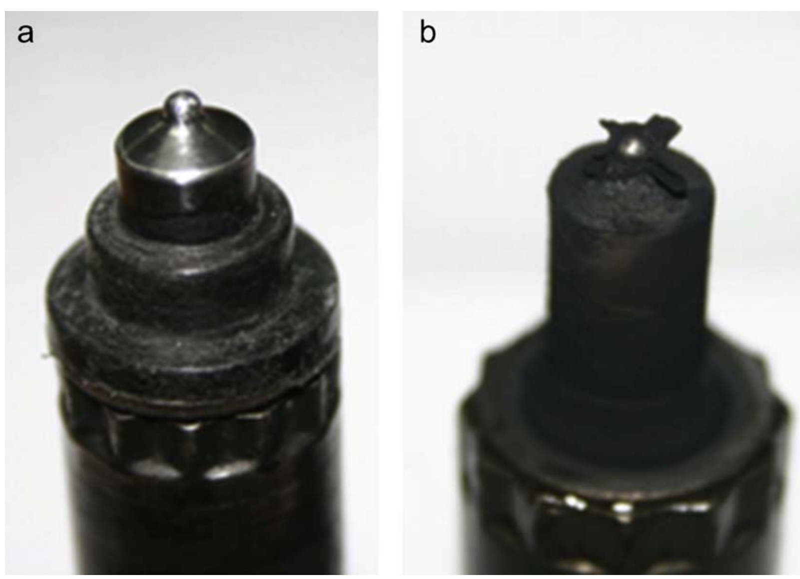


Fig. 16. Carbon deposition in injector tip after using: (a) no. 2 diesel, (b) 95% no. 2 diesel and 5% palm olein [100].

chain countrywide. Geographically palm plantations are scattered all over Malaysia and Indonesia. If large scale process plants are distributed in all parts of the country, securing a supply line will not be a tough call. But motivating to the market, a price drive has to be created by automobile sales with dedicated biodiesel engine. Even though there are many European and American auto manufacturer certifies biodiesel use in their diesel engines, but they are very strict on their standards and most of them do not have after sales service in Malaysia and Indonesia. So a dedicated biodiesel engine marketed by a local auto manufacturer will boost user confidence. On the way to build a new biodiesel engine, certain research approaches should be undertaken simultaneously. In Fig. 18 three different folds of research approach is shown. A higher yielding production process will certainly reduce the price of palm biodiesel. Research on modification of

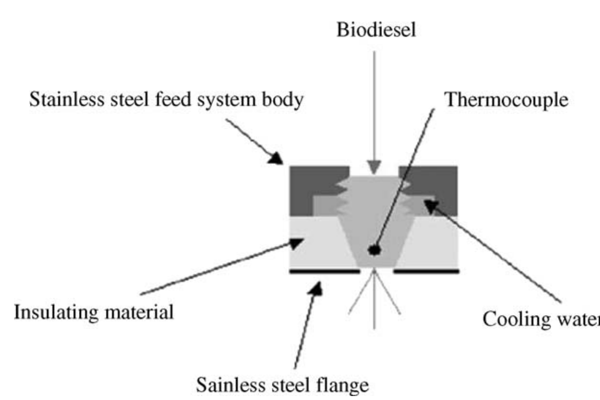


Fig. 17. Sgroi et al. [102] proposed injector for biodiesel operation.

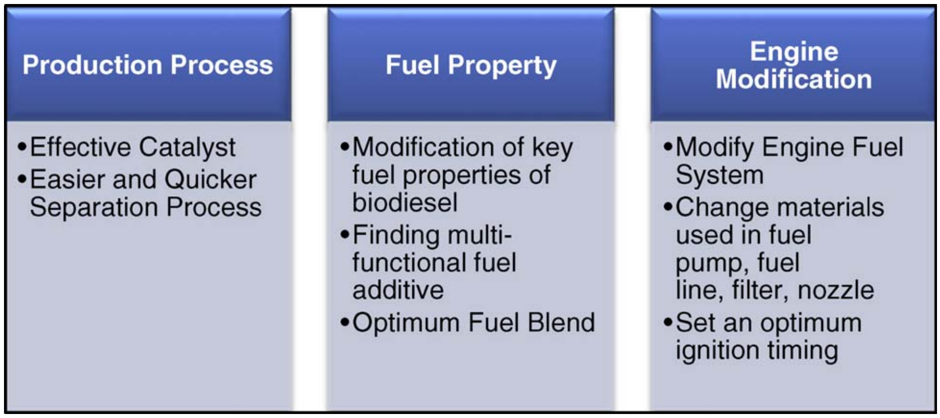


Fig. 18. Threefold research approach for dedicated biodiesel engine.

fuel property will reduce the adverse effect on the engine. Lastly, engine fuel supply system should be modified both by design and incorporating new materials.

A green car dream is not far from reality, if all the gaps between inventor, innovator and investor is removed, as mentioned by Gebeshuber et al. [105]. Here the government has to play its role on planning and putting all together, researchers, car manufacturers and oil companies. Apart from making the target only, they have to invest on research works as well as stimulate farming of palm nationwide.

8. Conclusions

Current trends in energy consumption are neither secure nor sustainable—environmentally, economically or socially. A forthcoming energy crisis will seize our social and economic growth if we do not change our usual practice and selection of energy source. Projections show a severe shortage of petroleum fuels is unenviable in near future with a drastic environment change. So in surge of alternative fuel many potential sources came out. Wind, solar, tidal and fusion energy are very prospective. But for a growing demand of transport fuel for millions of automobiles, we need an alternative that can easily adapt with the present supply and storing system. Biodiesel is that fuel which is fungible to diesel in diesel engines with little modification. Different research and development approaches on biodiesel shows, diesel engines designed for no. 2 diesel does not suite for long time engine operation. Hence little modification can give a comprehensive solution in tailoring fuel properties for engine compatibility. Brazil had been most successful in using bioethanol by producing flexi-fuel vehicles. On the contrary, biodiesel do not have any modified vehicle patent so far. Considering all pros and cons and fuel properties this can be comprehended that multi-functional fuel additives may make biodiesels more engine compatible, but it will increase its price. So a mass production along with utilization needs a dedicated engine which could be converted from present day diesel engines after little modification on fuel supply system only.

Acknowledgements

The authors would like to acknowledge Ministry of Science, Technology and Innovation (MOSTI) for the project: 03-01-03-SF0433 and University of Malaya for the financial support through PPP grant no. PS074-2009B and excellent research environment.

References

[1] Kurani KS, Sperling D. Rise and fall of diesel cars: a consumer choice analysis. Transpotation Research Record 1988;1175:23–32.
[2] Walsh MP. Global trends in diesel emissions control—a 1999 update. SAE Tech Paper No 1999-01-0107 1999.
[3] Nitschke WR, Wilson CM. Rudolph diesel, pioneer of the age of power. Norman (OK): The University of Oklahoma Press; 1965.
[4] Agarwal AK. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. Progress in Energy and Combustion Science 2007;33(3):233–71.
[5] Ma F, Hanna MA. Biodiesel production: a review. Bioresource Technology 1999;70(1):1–15.
[6] Harwood HJ. Oleochemicals as a fuel: mechanical and economic feasibility. Journal of the American Oil Chemists' Society 1984;61(2):315–24.
[7] De B, Bhattacharyya D, Bandhu C. Enzymatic synthesis of fatty alcohol esters by alcoholysis. Journal of the American Oil Chemists' Society 1999;76(4):451–3.
[8] Selmi B, Thomas D. Immobilized lipase-catalyzed ethanolysis of sunflower oil in a solvent-free medium. Journal of the American Oil Chemists' Society 1998;75(6):691–5.
[9] Demirbas A. Biodiesel. London: Springer; 2008. p. 114–5.
[10] Masjuki H. Biofuel as diesel fuel alternative: an overview. Journal of Energy Heat and Mass Transfer 1993;15:293–304.
[11] May CY, Ngan MA, Yoo CK, Majid RA, Chung AYK, Nang HLL, et al. Palm diesel: green and renewable fuel from palm oil. MPOB Bulletin/Information Series 2005.
[12] Masjuki H, Sapuan S. Palm oil methyl esters as lubricant additive in a small diesel engine. Journal of the American Oil Chemists' Society 1995;72(5):609–12.
[13] Yudhoyono SB. State address of the president of the republic of Indonesia and the government statement on the bill on the state budget for the 2007 fiscal year and its financial note before. Jakarta: The Plenary Session of The House of Representatives; 2006.
[14] Agra IB. Ethanolysis of Jatropha curcas oil at higher pressure using sodium hydroxide as catalyst. In: Proceedings of the 2nd ASEAN Renewable Energy Conference; 1997.
[15] Zhou A, Thomson E. The development of biofuels in Asia. Applied Energy 2009;86(Suppl. 1):S11–20.
[16] Tan KT, Lee KT, Mohamed AR, Bhatia S. Palm oil: addressing issues and towards sustainable development. Renewable and Sustainable Energy Reviews 2009;13(2):420–7.
[17] Salunkhe DK, Chavan JK, Adsule RN, Kadam SS. World oilseeds: chemistry, technology, and utilization. Springer; 1992. p. 545.
[18] Vanichseni T, Intaravichai S, Saitthiti B, Kiatiwat T. Potential biodiesel production from palm oil for Thailand. Kasetsart Journal Natural Sciences 2002;36(1):83–97.
[19] Loh SK, Choo YM, Cheng SF, Ma AN. Recovery and conversion of palm olein-derived used frying oil to methyl esters for biodiesel. Journal of Oil Palm Research 2006;18(June):247–52.
[20] Hoekman SK. Biofuels in the U.S.—challenges and opportunities. Renewable Energy 2009;34(1):14–22.
[21] Abdullah K. Renewable energy conversion and utilization in ASEAN countries. Energy 2005;30(2–4):119–28.
[22] Legowo EH, Kussuryani Y, Reksowardojo IK. Biofuel development in Indonesia. In: USDA global conference on agricultural biofuels: research and economic; 2007.
[23] Comparative LCA analysis of different edible oils and fats. International palm oil sustainability conference, Available at: http://www.mpoc.org.my, 2008.
[24] Sperling Daniel, Gordon D. Two billion cars: driving toward sustainability. New York: Oxford University Press; 2009. pp. 95–6. ISBN 9780195376647.

[25] Rico JAP, Programa de Biocombustíveis no Brasil e na Colômbia: uma análise da implantação, resultados e perspectivas" (in Portuguese). Universidade de São Paulo. http://www.teses.usp.br/teses/disponiveis/86/86131/tde-07052008-115336/. Accessed on 5 October, 2008. Ph.D. Dissertation Thesis, 2008: 81–2.
[26] Yan J, Lin T. Biofuels in Asia. Applied Energy 2009;86(Suppl. 1):S1–0.
[27] Badawi AHA, Speech in Dewan Raktay: ninth Malaysia plan 2006–2010. Speech By The Prime Minister 31 March 2006 [cited http://www.utusan.com.my/utusan/SpecialCoverage/RMK9/html/english.htm].
[28] Oh TH, Pang SY, Chua SC. Energy policy and alternative energy in Malaysia: issues and challenges for sustainable growth. Renewable and Sustainable Energy Reviews 2010;14(4):1241–52.
[29] National Energy Balance (NEB) Publication. Malaysia energy database and information system (MEDiS); 2006.
[30] Renewable fuel in emerging markets: gearing global biodiesel production trough Malaysian palm oil. Malaysia Palm Oil Council; 2008.
[31] Lopez GP, Laan T. Biofuels-at what cost? Government support for biodiesel in Malaysia.. Global Subsidies Initiatives; 2008 [Accessed in 12 March, 2009]; http://www.globalsubsidies.org/en/research/biofuel-subsidies.
[32] Dillon HS, Laan T, Dillon HS. Biofuels-at what cost? Government support for biodiesel in Indonesia.. Global Subsidies Initiatives; 2008 [Accessed in 12 March, 2009]; http://www.globalsubsidies.org/en/research/biofuel-subsidies.
[33] Strategic plan for new and renewable energy of Indonesia. Directorate General of Electricity and Energy Utilization; 2007.
[34] Yudhoyono SB. State address of the president of the Republic of Indonesia and the government statement on the bill on the state budget for the 2007 fiscal year and its financial note before the plenary session of the house of representatives of the Republic of Indonesia, August 16, 2006; 2006, Jakarta.
[35] Yusgiantoro P, Indonesia's experience on biofuels development, in International biofuels conference, P.b.I.M.o.E.a.M. Resources, 5 July 2007: Brussels.
[36] Directorate general of electricity and energy utilization. Strategic Plan for New and Renewable Energy of Indonesia; 2007.
[37] Department of energy and mineral resources, in year 2009 oil fuel subsidy is reduced to Rp. 100.6 trillion. 12 September 2008: Jakarta.
[38] Bromokusumo AK. Indonesia Bio-fuels annual. GAIN report. USDA Foreign Agricultural Service 2008;September:3–4.
[39] NIST. White paper on internationally compatible biofuel standards, tripartite task force Brazil. European Union & United States of America; 2007[Accessed on 2 February 2009]; www.nist.gov/public_affairs/biofuels_report.pdf.
[40] Mittelbach M. Diesel fuel derived from vegetable oils. VI. Specifications and quality control of biodiesel. Bioresource Technology 1996;56(1):7–11.
[41] Canakci M. The potential of restaurant waste lipids as biodiesel feedstocks. Bioresource Technology 2007;98(1):183–90.
[42] Mittelbach M, Gangl S. Long storage stability of biodiesel made from rapeseed and used frying oil. Journal of the American Oil Chemists' Society 2001;78(6):573–7.
[43] Mittelbach M, Wörgetter M, Pernkopf J, Junek H. Diesel fuel derived from vegetable oils: preparation and use of rape oil methyl ester. Energy in Agriculture 1983;2:369–84.
[44] Gerpen JV. In: Cundiff EEG, Hansen C, Peterson C, Sanderson MA, Shapouri H, VanDyne DL, editors. Cetane number testing of biodiesel, in Third liquid fuel conference: liquid fuel and industrial products from renewable resources. St. Joseph, MI: American Society of Agricultural Engineers; 1996 . pp. 197–206..
[45] Cheah KY, Choo YM, Ngan MAA H, Yusof B. Production technology of palm diesel. Production technology of palm diesel Malaysia 1998;5:207–26.
[46] Koltsakis GC, Stamatelos AM. Catalytic automotive exhaust aftertreatment. Progress in Energy and Combustion Science 1997;23.
[47] Sarin A, Arora R, Singh NP, Sharma M, Malhotra RK. Influence of metal contaminants on oxidation stability of Jatropha biodiesel. Energy 2009;34(9):1271–5.
[48] Jayed MH, Masjuki HH, Saidur R, Kalam MA, Jahirul MI. Environmental aspects and challenges of oilseed produced biodiesel in Southeast Asia. Renewable and Sustainable Energy Reviews 2009;13(9):2452–62.
[49] Srivastava A, Prasad R. Triglycerides-based diesel fuels. Renewable and Sustainable Energy Reviews 2000;4(2):111–33.
[50] Gryglewicz S. Rapeseed oil methyl esters preparation using heterogeneous catalysts. Bioresource Technology 1999;70(3):249–53.
[51] Furuta S, Matsuhashi H, Arata K. Biodiesel fuel production with solid superacid catalysis in fixed bed reactor under atmospheric pressure. Catalysis Communications 2004;5(12):721–3.
[52] Vicente G, Martínez M, Aracil J. Integrated biodiesel production: a comparison of different homogeneous catalysts systems. Bioresource Technology 2004;92(3):297–305.
[53] Formo MW. Ester reactions of fatty materials. Journal of the American Oil Chemists' Society 1954;31(11):548–59.
[54] Murugesan A, Umarani C, Chinnusamy TR, Krishnan M, Subramanian R, Neduzchezhain N. Production and analysis of bio-diesel from non-edible oils–A review. Renewable and Sustainable Energy Reviews 2009;13(4):825–34.
[55] Barnwal BK, Sharma MP. Prospects of biodiesel production from vegetable oils in India. Renewable and Sustainable Energy Reviews 2005;9(4):363–78.
[56] Demirbaş A. Diesel fuel from vegetable oil via transesterification and soap pyrolysis. Energy Sources Part A Recovery Utilization and Environmental Effects 2002;24(9):835–41.
[57] Kramer P, Vogel H. Hydrolysis of esters in subcritical and supercritical water. Supercrit Fluids 2000;16:189–206.
[58] Kusdiana D, Saka S. Kinetics of transesterification in rapeseed oil to biodiesel fuel as treated in supercritical methanol. Fuel 2001;80(5):693–8.
[59] Karel K, Jaroslav M, Radek S. Biodiesel from rapeseed oil, methanol and KOH. 2. Composition of solution of KOH in methanol as reaction partner of oil. European Journal of Lipid Science and Technology 2001;103(6):359–62.
[60] Knothe G, Krahl J, Van Gerpen J. The biodiesel handbook. Champaign (IL): AOCS Press; 2006.
[61] Mudge SM, Pereira G. Stimulating the biodegradation of crude oil with biodiesel: preliminary results. Spill Science Technology Bulletin 1999;5:353–5.
[62] Zhang Y, Dubé MA, McLean DD, Kates M. Biodiesel production from waste cooking oil. 1. Process design and technological assessment. Bioresource Technology 2003;89(1):1–16.
[63] Knothe G, Sharp CA, Ryan TW. Exhaust emissions of biodiesel, petrodiesel. Neat methyl esters, and alkanes in a new technology engine. Energy & Fuels 2005;20(1):403–8.
[64] Mittelbach M, Remschmidt C. Biodiesels—the comprehensive handbook. Graz, Austria: Karl-Franzens University Press; 2004.
[65] Labeckas G, Slavinskas S. Performance of direct-injection off-road diesel engine on rapeseed oil. Renewable Energy 2006;31(6):849–63.
[66] Ramadhas AS, Jayaraj S, Muraleedharan C. Characterization and effect of using rubber seed oil as fuel in the compression ignition engines. Renewable Energy 2005;30(5):795–803.
[67] Nag A, Bhattacharya S, De K. New utilization of vegetable oils. Journal of the American Oil Chemists' Society 1995;72(12):1591–3.
[68] Schlick KL, Hanna MA, Schinstock JL. Soybean and sunflower oil performance in a diesel engine. Transactions of the ASAE 1988;31(5):1345–9.
[69] Pestes MN, Stanislao J. Piston ring deposits when using vegetable oil as a fuel. Journal of Testing and Evaluation 1984;12(2):61–8.
[70] Kalam MA, Masjuki HH. Emissions and deposit characteristics of a small diesel engine when operated on preheated crude palm oil. Biomass and Bioenergy 2004;27(3):289–97.
[71] Engler C, Johnson L, Lepori W, Yarbrough C. Effects of processing and chemical characteristics of plant oils on performance of an indirect-injection diesel engine. Journal of the American Oil Chemists' Society 1983;60(8):1592–6.
[72] Jones ST, Peterson CL, Thompson JC, Used vegetable oil fuel blend comparisons using injector coking in a di diesel engine. 30 July 01 August, 2001, Paper number: 01-6051, An ASAE Annual International Meeting Presentation, Sacramento, CA, USA. p. 26.
[73] Rathore V, Madras G. Synthesis of biodiesel from edible and non-edible oils in supercritical alcohols and enzymatic synthesis in supercritical carbon dioxide. Fuel 2007;86.
[74] Ryan T, Dodge L, Callahan T. The effects of vegetable oil properties on injection and combustion in two different diesel engines. Journal of the American Oil Chemists' Society 1984;61(10):1610–9.
[75] Peterson C, Auld D, Korus R. Winter rape oil fuel for diesel engines: recovery and utilization. Journal of the American Oil Chemists' Society 1983;60(8):1579–87.
[76] Pryor RW, Hanna MA, Schinstock JL, Bashford LL. Soybean oil fuel in a small diesel engine. Trans ASAE 1982;26(2):333–8.
[77] Bruwer JJ, Boshoff BvD, Hugo FJC, Fuls J, Hawkins C, Walt ANvd, et al. Utilization of sunflower seed oil as a renewable fuel for diesel engines. ASAE Publication 1981;2:385–90.
[78] Van der Walt A, Hugo F. Diesel engine tests with sunflower oil as an alternative fuel. In: Beyond the energy crisis-opportunity and challenge volume, third international conference on energy use management; 1981.
[79] Perkins L, Peterson C, Auld D, Durability testing of transesterified winter rape oil (*Brassica napus* L.) as fuel in small bore, multi-cylinder, DI, CI engines. SAE Technical Paper No. 911764, selected for reprinting in SAE 1991. Transactions Journal of Fuels and Lubricants, 1991.
[80] Reid J, Hansen A, Goering C. Quantifying diesel injector coking with computer vision. Transactions of the ASAE 1989;32(5):1503–6.
[81] Schlautman NJ, Schinstock JL, Hanna MA. Unrefined expelled soybean oil performance in a diesel engine. Transactions of the American Society of Agricultural Engineers 1986;29(1). 70-73, 80.
[82] Hofman, V., et al., Sunflower for power! 1981: Cooperative Extension Service, North Dakota State University.
[83] Prateepchaikul G, Apichato T. Palm oil as a fuel for agricultural diesel engines: comparative testing against diesel oil. Songklanakarin Journal of Science and Technology 2003;25(3).
[84] Baranescu RA, Lusco JJ. Performance, durability, and low temperature operation of sunflower oil as a diesel fuel extender, vegetable oil fuels. In: Proceedings of the international conference on plant and vegetable oils fuels, ASAE; 1982.
[85] Sims REH, Raine RR, McLeod RJ. Rapeseed oil as a fuel for diesel engines. SAE-Australia. National Conference on Fuels from Crops of the Society of Automotive Engineers 1981.
[86] Zieiwski, M Goettler J, Design modications for durability improvements of diesel engines operating on plant fuels. SAE, 1992. No. 921630.
[87] Tahir AR, Lapp HM, Buchanan LC. Sunflower oil as a fuel for compression ignition engines. In: Vegetable oil fuels: proceedings of the international conference on plant and vegetable oils fuels; 1982.

[88] Peterson C, Thompson J, Wagner, G, Auld D, Korus R. Extraction and utilization of winter rape (Brassica napus) as a diesel fuel extender; 1982.
[89] Silvico CA, Carlos R, Marious VG, Leonardodos SR, Guilherme F. Performance of a diesel generator fueled with palm oil. Journal of Fuels 2002;81(6):2097–102.
[90] Brink A, Jordaan CFP, Le Roux JH, Loubser NH. Carburetor corrosion: the effect of alcohol-petrol blends.. In: Proceedings of the VII international symposium on alcohol fuels technology; 1986. p. 59–62.
[91] Allsup JR, Emissions, efficiency, and durability of agricultural diesel engines using low-proof ethanol. in SAE Technical Paper Series. 1983. Milwaukee, WI, USA: SAE.
[92] Bosch, VP44 endurance test with E diesel. Internal Report No. 00/47/3156. Robert Bosch Corporation, Farmington Hills, MI, USA, 2001.
[93] Fitzherbert EB, Struebig MJ, Morel A, Danielsen F, Brühl CA, Donald PF, et al. How will oil palm expansion affect biodiversity? Trends in Ecology & Evolution 2008;23(10):538–45.
[94] Lian Pin K, David SW. Is oil palm agriculture really destroying tropical biodiversity? Conservation Letters 2008;1(2):60–4.
[95] Corley RHV, Tinker PB. The oil palm. Blackwell Science; 2003.
[96] Wood BJ, Fee CG. A critical review of the development of rat control in Malaysian agriculture since the 1960s. Crop Protection 2003;22(3):445–61.
[97] Page SE, Siegert F, Rieley JO, Boehm H-DV, Jaya A, Limin S. The amount of carbon released from peat and forest fires in Indonesia during 1997. Nature 2002;420(6911):61–5.
[98] Wicke B, Dornburg V, Junginger M, Faaij A. Different palm oil production systems for energy purposes and their greenhouse gas implications. Biomass and Bioenergy 2008;32(12):1322–37.
[99] Husnawan M, Masjuki HH, Mahlia TMI, Saifullah MG. Thermal analysis of cylinder head carbon deposits from single cylinder diesel engine fueled by palm oil-diesel fuel emulsions. Applied Energy 2009;86(10): 2107–13.
[100] Saifullah MG, Performance and carbon deposit study of a single cylinder diesel engine with refined palm olein and additive blended diesel fuel, Department of Mechanical Engineering University of Malaya: Kuala Lumpur; 2009.
[101] Goto, S, Oguma M, Chollacoop N, Benchmarking of biodiesel fuel standardizations in east Asia, in 6th Biomass Asia workshop. 2009: Hiroshima, Japan.
[102] Sgroi M, Bollito G, Saracco G, Specchia S. BIOFEAT: biodiesel fuel processor for a vehicle fuel cell auxiliary power unit: study of the feed system. Journal of Power Sources 2005;149:8–14.
[103] Graboski MS, McCormick RL. Combustion of fat and vegetable oil derived fuels in diesel engines. Progress in Energy and Combustion Science 1998;24:125–64.
[104] MacLeana HL, Lave LB. Evaluating automobile fuel/propulsion system technologies. Progress in Energy and Combustion Science 2002;29:1–69.
[105] Gebeshuber IC, Gruber P, Drack M. A gaze into the crystal ball—biomimetics in the year 2059. 50th Anniversary Issue. Proceedings of the Instrumental Mechanical Engineering 2009.